

Assessing internal conditions in typical housing built to Passivhaus Standard in Jakarta, Indonesia - analysis for a hot humid, tropical season

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Abstract

Properly designed ventilation in a house built in a hot and humid climate will provide adequate fresh air, but during hot weather this ventilation will introduce more moisture in to the house. Also, approximately 30–50% of the energy used for air conditioning for cooling is lost through air infiltration. These issues could possibly be addressed by making the envelope of tropical housing more air-tight. The objective of this study was to determine energy-saving modifications through the application of Passivhaus principles to Jakarta urban houses. This paper investigated the effects on indoor temperature, humidity, comfort and energy use of gradually improving insulation levels and airtightness to meet the Passivhaus standard. This study analysed the effects of air conditioning (AC) and dehumidifiers on thermal comfort and cooling load through numerical simulation using IES VE software. Some design recommendations result from the analysis.

Keywords Passivhaus, Hot and humid climate, Dehumidification, tropical climate, Low energy building

1.0 Introduction

Indonesia, according to the Köppen-Geiger climate classification system, lies within the equatorial rainforest, fully humid zone (1). The climate is generally hot and humid, with only a small variation of temperature throughout the year. The minimum average temperature is 23°C, the maximum average temperature is 33°C, the average relative humidity is between 69% and 90%, and the average wind velocity is between 0.2 and 0.8 m/s (2). Most Indonesian regions experience rainfall between 1000 and 4000 mm/year.

A preference for low-density housing by Indonesians has contributed greatly to uncontrolled urban sprawl around the peripheries of Indonesia's major cities (3). During the hot season, the application of simple cooling measures, such as glazing, shading, insulation, and natural ventilation, to these dwellings can reduce the cooling loads by up to 43% (4). Ventilation of a tropical house with proper design will provide enough fresh air to keep the occupants healthy, to remove odours and to dilute indoor pollutants. But with high outdoor relative humidity, ventilations are not able to reduce internal relative humidity. Any design approaches to the building that are able to bring comfort to the rooms and are energy efficient are very important. One radical alternative solution is to apply the German Passivhaus standard to Indonesian dwellings.

1.1 Passivhaus definition

The Passivhaus standard was established as a building concept for residential buildings in Germany. Generally, the Passivhaus standard delivers excellent cost-effectiveness, especially in the case of new build. The general criteria of Passivhaus can be seen on Table 1 (5). The success in the first Passivhaus projects, with very low energy consumption and high thermal comfort levels, has stimulated the spread of the Passivhaus standard to other countries in Europe and beyond. Thousands of certify Passivhaus dwellings are located in Europe, and there are also some in the USA, East Asia, and Australia (6). Even though the initial developments were made within Central and Northern Europe, the findings suggested that the market for Passivhaus should not just be limited to Central Europe, and that the ultra-low energy standard could be a feasible option in different climates (7).

			Criteria ¹		Alternative Criteria ²	
Heating						
Heating demand	[kWh/(m²a)]	≤	15		-	
Heating load ³	[W/m²]	≤	-		10	
Cooling						
Cooling + dehumidification demand	[kWh/(m²a)]	≤	15 + dehumidification contribution ⁴		variable limit value ⁵	
Cooling load ⁶	[W/m²]	≤	-		10	
Airtightness						
Pressurization test result n ₅₀	[1/h]	≤	0.6			
Renewable Primary Energy (PER)⁷						
			Classic	Plus	Premium	±15 kWh/(m²a) deviation from criteria... ...with compensation of the above deviation by different amount of generation
PER demand ⁸	[kWh/(m²a)]	≤	60	45	30	
Renewable energy generation ⁹ (with reference to projected building footprint)	[kWh/(m²a)]	≥	-	60	120	

Table 1 – Passive House Criteria

Thermal comfort in a Passivhaus building is achieved mainly by passive measures, for instance high levels of insulation, excellent airtightness, good indoor air quality, minimal thermal bridges and a whole house mechanical ventilation system with highly efficient heat recovery (8). This building standard is an effective tool to preserve stable interior temperatures, but its air-tight envelope might hinder the removal of excess moisture in tropical climates. The Passive-On study forecast a number of issues related to Passivhaus criteria for warmer climates. These included the introduction of a limit for energy demand for summer cooling, a relaxed infiltration rate and an indoor comfort temperature that coincided with adaptive thermal comfort standards (9). The application of the Passivhaus standard must properly consider moisture balances and the attendant latent loads on the building with a hot and humid climate.

1.2 Passivhaus cooling

Various kinds of heat exchangers have been commonly used in air conditioning systems for coolness recovery. The cooling strategy used by one of the certified Passivhaus offices in a hot and humid climate, the Austrian Embassy in Jakarta, was the Concrete Core Temperature Control or CCTC (10). The base load for the cooling supply is covered by a chiller. It provides gentle radiant cooling by pumping cool water into pipes cast inside the floor, instead of a cold air breeze from split units. A mean temperature of 25°C, and 60% humidity is guaranteed, together with a good supply of fresh air (11). The embassy's cooling energy costs are less than an ordinary office block, and it emits less carbon (12). Another cooling strategy found for

a Passivhaus in a humid region is one located in Louisiana, southern USA. The cooling and dehumidifying in this building are as much of a challenge as heating, with Energy Recovery Ventilators (ERV) being used. Unlike straight heat exchangers, ERV also transfers water vapour, which prevents the air from drying out in winter months, and removes outdoor humidity during summer months (13). However, in a hot and humid climate, the incoming outdoor air can only possibly be cooled by the outgoing exhaust air in an air-conditioned house (14). ERV systems are not dehumidifiers, and they transfer moisture from incoming humid air to the stale indoor air that is being vented to the outside.

1.3 Thermal Comfort

The importance of indoor thermal comfort assessment and measurement is not only related to thermal satisfaction achievement; it is also to control energy usage and enhance indoor air quality (15). Table 2 shows three main categories that affect thermal comfort in any given space: environmental, personal and other contributing factors (16). The effect of air movement and humidity are particularly important in hot climates where the heat lost by evaporation predominates (17). The Indonesian National Standard (SNI) specifies the comfort temperature is $25^{\circ}\text{C} \pm 1^{\circ}\text{C}$ and relative humidity is $60\% \pm 10\%$ (18). The result from researchers who had researched on the comfort temperature for people in Depok area (Jakarta satellite town) indicate that the comfort temperature is higher than the national standard, which is 27.6°C (19).

Environmental	Personal	Contributing Factors
Air temperature	Metabolic Rate	Food and drink
Air movement	Clothing	Body shape
Humidity	State of health	Sub cutaneous fat
Radiation	Acclimatization	Age and gender

Table 2 – Factors affecting thermal comfort

2.0 Research methodology

This paper presents the results from an analysis of thermal comfort and energy efficiency after implementing the Passivhaus standard to a residential building in the hot and humid climate of Indonesia. The target houses chosen for analysis were row or terrace houses, which form most of the existing urban housing stock. The selected monitored house had a floor area between 50m^2 to 69m^2 floor area, where this is the most prevalent floor area range for housing in the Jakarta Metropolitan Region (20). By using building information such as building materials, cooling systems, lights and appliances, and a presupposed occupancy schedule from the selected house, a building model for computer simulation was made. The dwelling was modelled by using IES VE 2018 software, which is one of the integrated building performance analysis software to determine indoor temperatures, relative humidity and energy use. A Jakarta weather file was acquired through the climate-modelling software Meteororm (21). The empirical validation of the model designed in the software was determined by comparing the computer simulation results with field experiment data from the chosen house.

This validated model was then used to explore the effects on the indoor environment when applying the Passivhaus standard to the row house and to study the energy needed to achieve thermal comfort. The main goal of this study was to test the

potential application of the Passivhaus standard to Jakarta houses with tropical conditions.

2.1 Description of case study dwelling

The house measured 6 m x 10 m with a total floor area of 55m², and a floor-to-ceiling height of 2.85m. The building was oriented towards north and was not insulated, being constructed from a single layer of brick, with single glazing windows (Figure 1).

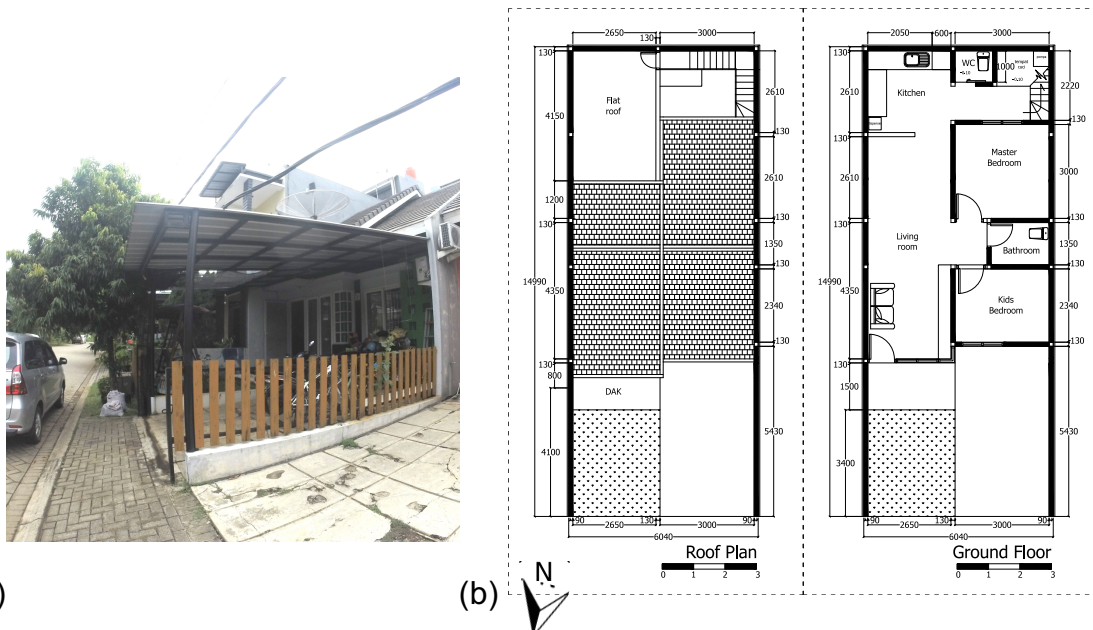


Figure 1 – The case study row house (a) exterior view, (b) floor plans

2.2 Monitoring the house

Monitoring of the selected row house was done for two selected periods, one in January – February for the rainy season, and the other one in September – November for the hot season. Monitoring of these parameters was undertaken by using loggers that were placed in the two main activity locations in the selected row house, that is the master bedroom and the living room, and one logger in an outdoor area (Figure 2). Two types of loggers were used in this monitoring - Tinytag data loggers and Rotronic data loggers. Loggers was used to measure the air temperature and relative humidity of the selected row house within the selected period.



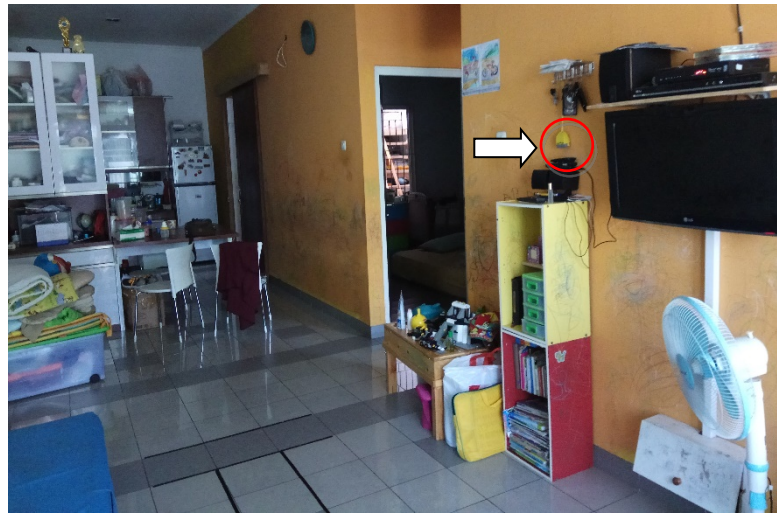


Figure 2 – Logger location in master bedroom, outdoor area and living room

2.3 Validation of the IES VE 2018 software

The empirical validation of the IES VE 2018 model was determined by comparing the simulation results with the house field measurement data. The simulation result was compared with measured period data in mid-September, which has relatively high weekly air temperature and a bigger range of temperature differences between maximum and minimum temperature compared to all the measured data. The whole house was modelled in three dimensions with IES VE software (Figure 3) using the data obtained from field observations. The building shape was based on the plan provided by the home owner, building materials based on the contractor specification, and the occupant activity schedule was gained from field observations. In order to make a comparison, the modelled house was then simulated for the same period as the monitoring time period. The building elements used to build the base model in IES VE 2018 can be seen in Table 3.

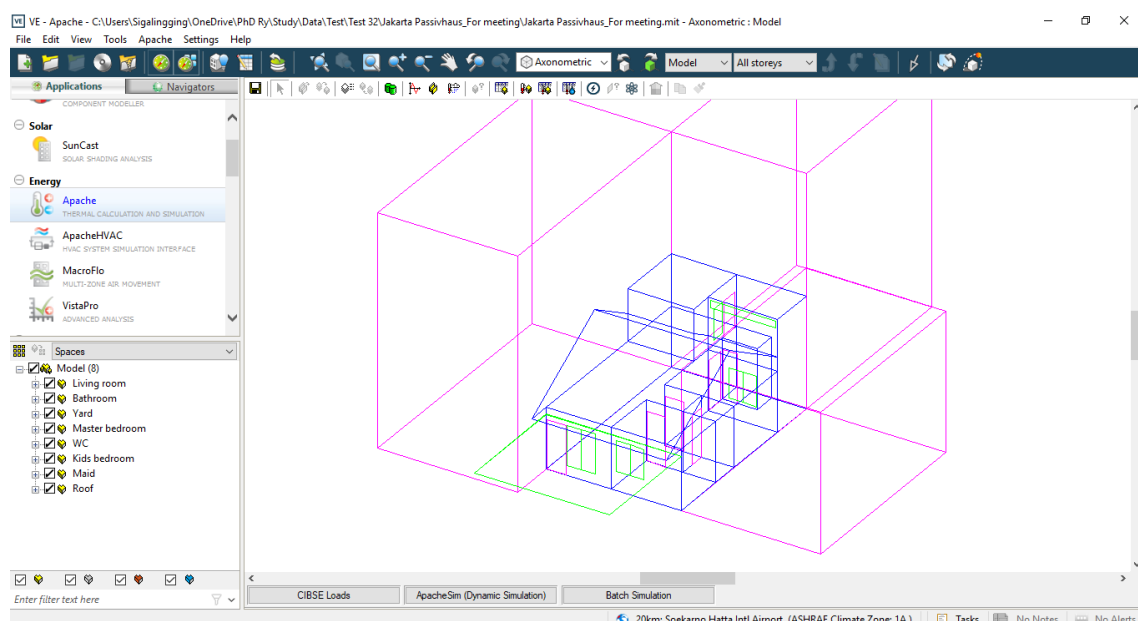
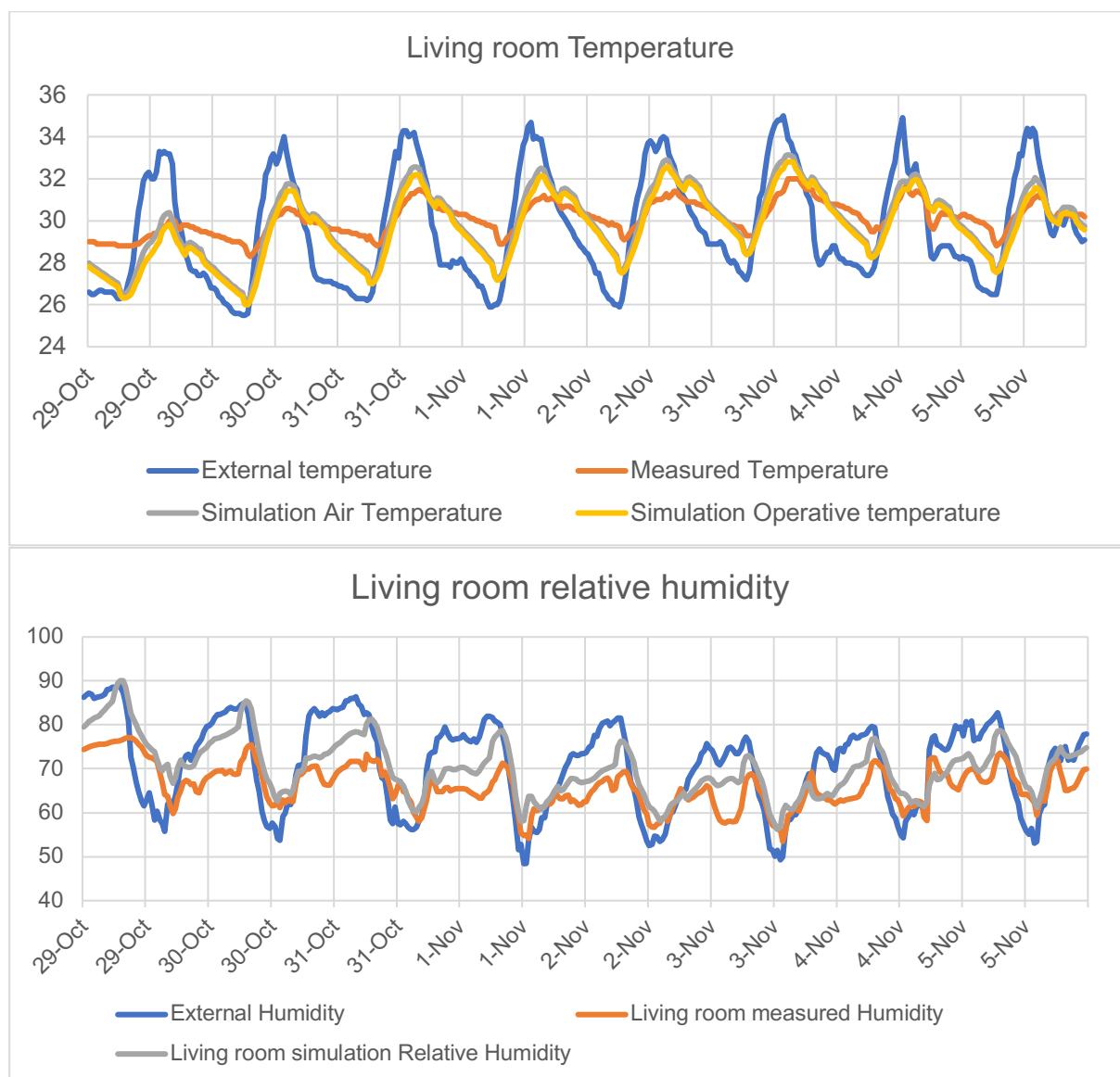


Figure 3 – House model in IES VE software

Building Element	Constructional layers
External and internal walls	25 mm thick cement plaster + 100 mm thick clay brick + 25 mm thick cement plaster
Party wall	25 mm thick cement plaster + 100 mm thick clay brick + 25 mm thick cement plaster
Floor	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + soil layer
Window	6 mm thick single layer glass
Ceiling	6 mm thick gypsum board
Pitched roof	20 mm thick roof tile + 25 mm thick timber batten
2 nd floor slab	22 mm thick cement screed + 100 mm thick concrete slab + 20 mm thick cement plaster

Table 3 – Building elements

The modelled house simulation results are compared with measured data and can be seen in Figure 4 and Figure 5. The validation simulation results show that the simulation results were satisfactory in displaying the same trends as the measured data.

**Figure 4 – Measurements and simulation data comparison in living room**

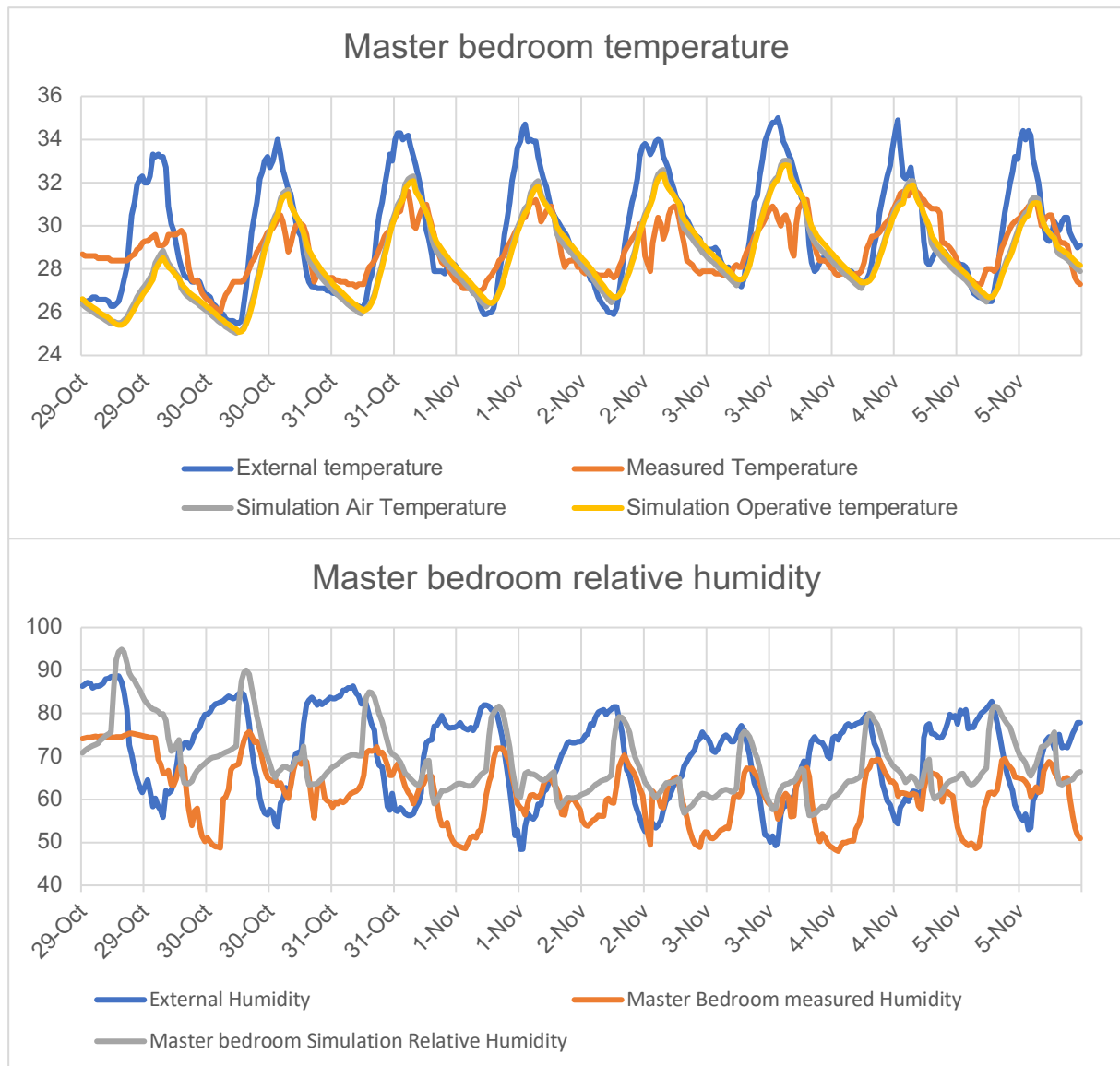


Figure 5 – Measurements and simulation data comparison in master bedroom

Living room results in Figure 4 indicate that the IES simulation results show the same fluctuation with the measured data, both for air temperature and relative humidity. The differences in the air temperature were around 1 to 2 °C, and around 10% for the relative humidity. In the bedroom area, the air temperatures had the same fluctuation between the modelled house simulation results with the measured data. On the other hand, there were a few days indicating relative humidity differences in the bedroom, where at 9.00 pm until 6.00 am there was a 10% drop in the simulated room relative humidity values. The temperature differences are possible from the actual sky coverage and wind speed data that is not capture on the site measurement. The other possible reason for the temperature and humidity differences are from occupant activity that made typical on the simulation, but on the actual condition might be slightly different from day to day. From this validation exercise, can be seen that the IES VE 2018 software can model the selected house in the tropical climate and produced relatively similar results compared with the field measurement data.

The loggers used in this study recorded air temperature. Operative temperature is often considered a better indicator of thermal comfort as it combines both air and mean radiant temperatures in a space, but is not easy to measure in real building

situations. The IES software was run to test for any significant differences between predicted air and operative temperatures in the house. However, as shown in Figure 6, there were only minor differences and so it was feasible to use air temperature for the validation and the comfort analysis. The closeness of the two temperatures may be because the tropical conditions make all internal surfaces warm and the glazing area was relatively modest, leading to the air temperature being similar to the mean radiant temperature.

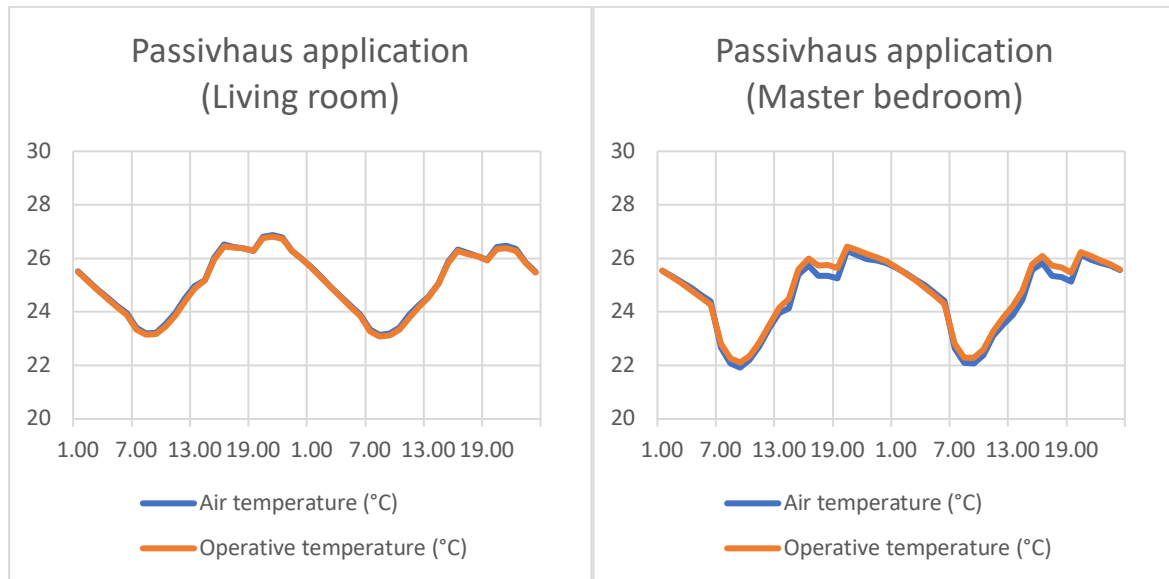


Figure 6 – Air temperature and operative temperature comparison

3.0 Passivhaus in tropical climate simulation result

3.1 Application of Passivhaus standard into modelled house

The validated house model house in IES VE 2018 was then used to study the application of the Passivhaus standard. A Through IES VE 2018 simulation, the building performance was observed when the Passivhaus standards were applied. The same building layout, shape, and occupancy schedule were used while one or more Passivhaus criteria were applied to explore the effect of Passivhaus standards on the modelled house whilst trying to maintain the house's internal environment within the thermal comfort zone. This study analysed the effects of air conditioning (AC) and dehumidifiers on thermal comfort and cooling load.

Building Element	Constructional layers
External and internal walls	25 mm thick cement plaster + 100 mm thick clay brick + 100 mm XPS Extruded Polystyrene + 25 mm thick cement plaster
Party wall	25 mm thick cement plaster + 100 mm thick clay brick + 100 mm XPS Extruded Polystyrene + 25 mm thick cement plaster
Floor	8 mm thick ceramic tile + 22 mm thick cement screed + 100 mm thick concrete slab + Urea Formaldehyde Foam + soil layer
Window	6 mm thick double layer glass
Ceiling	6 mm thick gypsum board
Pitched roof	20 mm thick roof tile + 25 mm thick timber batten + 100 mm MW Glass Wool (rolls)

Table 4 – Passivhaus building elements

The performance of the house with its original layout was compared with the performance of the building with the Passivhaus standard. Both scenarios used the same HVAC system (AC and dehumidifier) that was located in the living room, master bedroom, and children's bedroom. For the simulation, the AC temperature set point in the IES VE was set on 26°C, and relative humidity controller set on 60%. Table 4 indicates the materials that were used in the building model to follow the Passivhaus concept.

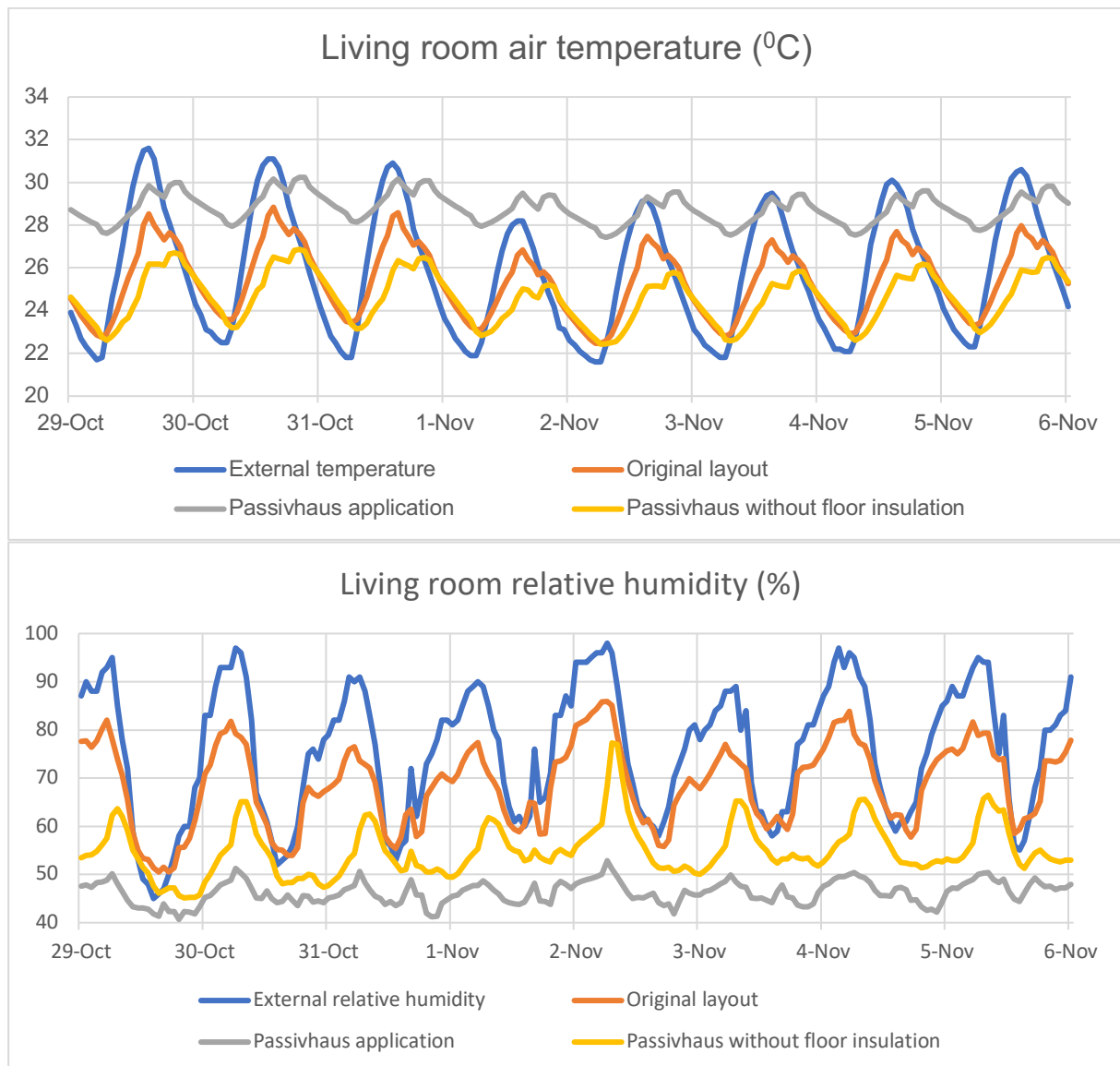


Figure 7 – Hourly air temperatures comparison in living room for Passivhaus approaches and original layout.

3.2 Comparing the simulation results

With the application of the Passivhaus standard to the wall and roof insulation, double-glazed windows and AC + dehumidifier, the IES VE 2018 simulation results showed that the Passivhaus building model had stable air temperatures for the whole day (Figures 7 and 8), even though the air temperature for this building models is still above 28 °C. For the original house scenario, the air temperature was still fluctuating and following the external air temperature, with a few hours being above 26 °C. The relative humidity for original house scenario is tracking outside relative humidity with

most of the time it's above 60%. On the other hand, the Passivhaus model indicated low relative humidity, with relative humidity always staying below 60% by using the AC+Dehumidifier system.

The analysis process was made by carefully applying Passivhaus concepts to a typical row house building model. At the time when Passivhaus building requirements were applied, but without floor insulation, the simulation result showed significant energy saving compared to the full Passivhaus building application. Therefore, in the simulation result comparison, there is one graph showing the Passivhaus application without floor insulation to indicate the differences. The analysis method for ground construction setting in IES VE are based on EN-ISO 13370 (22). This method takes as inputs ground conductivity, floorplan characteristic dimension, wall thickness, insulation details and depth below ground level.

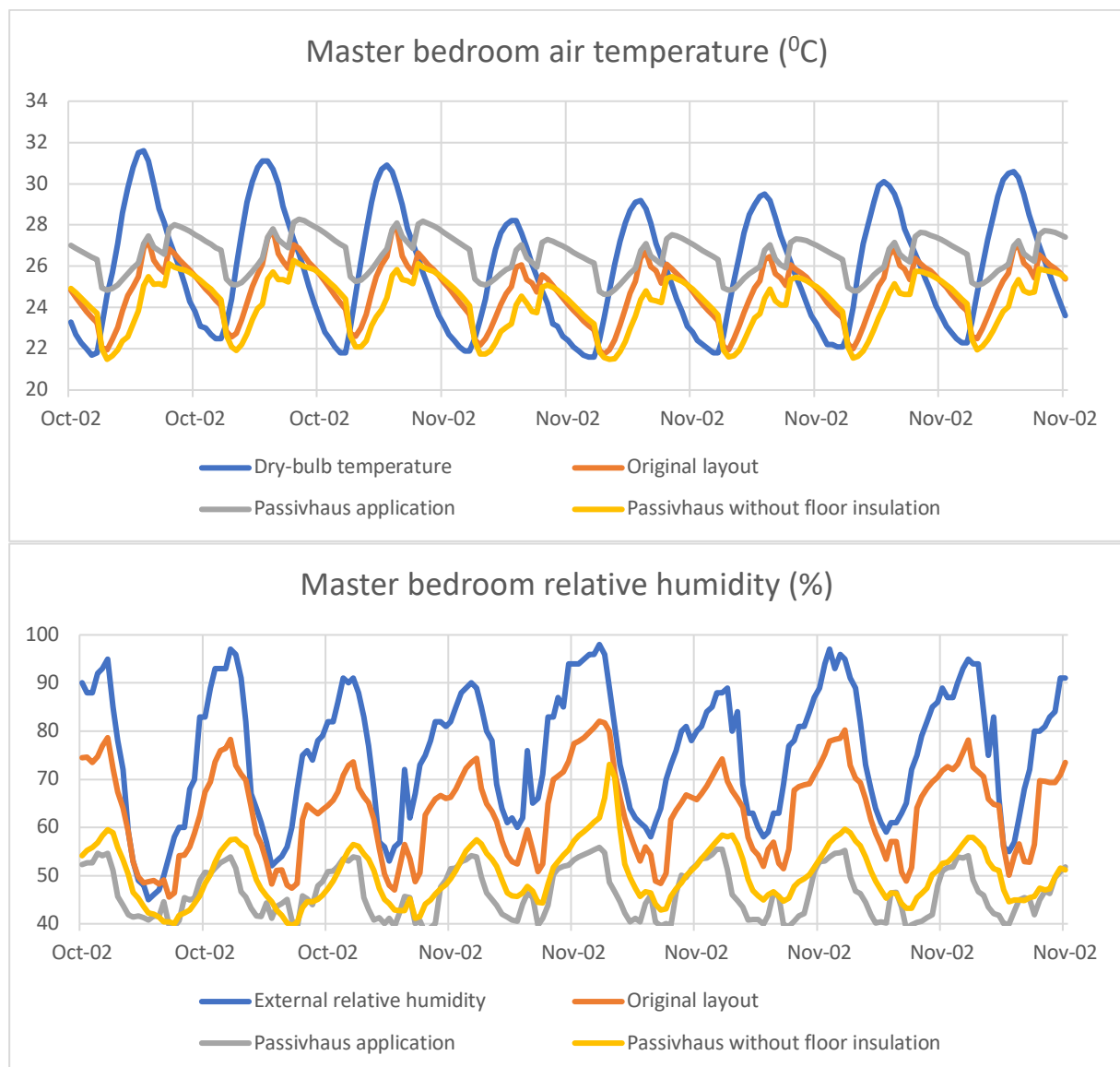


Figure 8 – Hourly air temperatures comparison in master bedroom for Passivhaus approaches and original layout.

The air temperature comparison (Figures 7 and 8) indicates that the Passivhaus house without floor insulation could lower the temperatures in the living room and

master bedroom to be always below 26°C for this selected period. Relative humidity for Passivhaus house without floor insulation also showed a stable level below 60%, which is in the comfort level zone for Jakarta. IES Simulation result also indicated that the annual cooling energy used in the building was 11.41 MWh for the original layout, 10.89 MWh for the house with Passivhaus application, and 8.61 MWh for the Passivhaus without floor insulation (Figure 9).

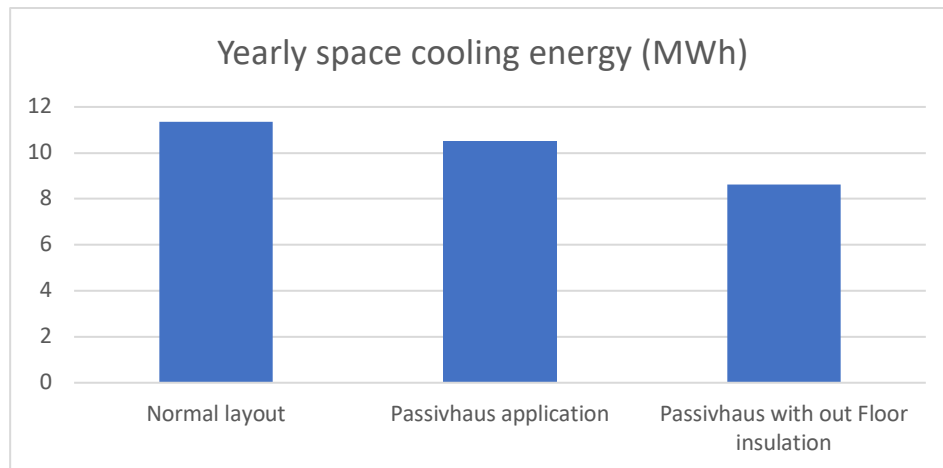


Figure 9 – Yearly space cooling energy use for the original house, the Passivhaus and the Passivhaus without floor insulation.

4.0 Conclusions and discussion

This paper explored the Passivhaus approach in a tropical climate building. Data from site measurements were used to validate a typical dwelling in the Jakarta Metropolitan Region that was modelled in IES VE 2018. This software was then used to study the output from the application of the Passivhaus standard on the IES VE's model house. The results showed that the building model in IES software for hot and humid climate was and could be used for further analysis of Passivhaus approaches. Cooling and dehumidification were key strategies in reducing relative humidity in the modelled house. The outdoor air should be cooled and dehumidified before it is circulated in the rooms. The current widely used and accepted technologies for removing air moisture are either direct cooling by chillers or desiccations. With IES VE simulation, dehumidification by using a desiccant dehumidifier can be simulated.

Based on the current analysis, after Passivhaus application into the modelled house by using AC and dehumidifier, the room temperature was still above 26 °C but the relative humidity could be kept below 60%. As the comfort temperature for Jakarta area is 25°C ± 1 °C, the room air temperatures of the Passivhaus building are still above comfort level. From the analysis, when applying Passivhaus into the building, but without floor insulation, indicated that for the whole day the rooms were at a comfort level. This scenario also had lower energy usage compared to Passivhaus with floor insulation and original layout. Removing the floor insulation in the Passivhaus building can lower the room temperature and maintain comfortable humidity's with much lower energy usage.

Further discussion on the cost issue is required. The application of the Passivhaus concepts in tropical climates still needs further analysis because the use of insulation, double glazing, and applying air-tight building is not a common practice in Indonesia. Besides the additional construction cost for the building, the quality of

construction workers needs to be improved, especially residential construction workers.

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